Introduction: Detailed knowledge of the lunar plasma environment is of critical importance to the design of human habitats or instruments for future lunar missions. While theories for the lunar plasma environment have been developed for decades, large scale numerical simulations of the lunar plasma have only recently become feasible. As a function of time and location, the lunar surface is exposed to solar wind plasma, UV radiation, and/or the plasma environment of our magnetosphere. Dust grains on the lunar surface collect electrostatic charges and contribute to the large-scale surface charge density distribution. They emit and absorb plasma particles and solar UV photons, and provide an electromagnetic interface to the lunar interior[1]. There are several in situ and remote sensing observations that indicate that dusty plasma processes are responsible for the mobilization and transport of the lunar soil. These processes remain among the least understood effects on the lunar surface. Effects like the charging process of the lunar surface, as well as individual dust grains in the near-surface plasma, the formation of the photoelectron sheaths, and the possible mobilization and lift-off of dust particles might play a possibly prohibitive role in our ability to develop sensitive in situ instrumentation, and/or human habitats.

To develop the appropriate in situ instrumentation for the observation of these processes, and to analyze and understand these measurements, there is an urgent need for theoretical models and computer simulations that account for the interactions between the surface and the plasma environment. Similarly, designing human habitats and protecting optical and mechanical devices on the moon poses various engineering challenges. In order to overcome these challenges, the properties of the lunar plasma environment have to be well understood.

Here we report on the initial results on using a sophisticated plasma simulation package to investigate these dusty plasma processes on the lunar surface. The large-scale parallel plasma modeling framework VORPAL, developed at the University of Colorado, Boulder, and Tech-X Corporation, offers the physical models to investigate this environment in a self-consistent way in both 2 and 3 dimensions [2].

Figure 2: Complex electromagnetic structure modeled with VORPAL. This capability enables electromagnetic simulations of the lunar plasma environment with detailed models of man-made structures.

Figure 1: VORPAL simulation of wake formation behind two dust grains in a plasma streaming from left to right. Bright colors indicate high net charge.

The VORPAL plasma simulation code: VORPAL offers both an electromagnetic and electrostatic model, which allows investigating effects solving the full set of Maxwell’s equations and problems where the magnetic induction can be neglected and computational time can be saved by solving Poisson’s equation instead [3]. The plasma can be treated either kinetically, as a fluid or as a combination with e.g. fluid electrons and kinetic ions. In addition to models for collisionless plasmas, VORPAL also features collisional processes, including impact ionization, recombination...
and charge exchange. Finally, the capability to model complex geometries enables to investigate the effects of dust on man-made structures.

**Figure 3:** VORPAL speedup for an electromagnetic problem with 784x512x512 grid cells on up to 16,848 processors at NERSC’s Cray XT/4 Franklin.

**Performance:** Kinetic simulations, which model the evolution of individual macro-particles in the electromagnetic field, require a large amount of computational power. In order to take advantage of largest supercomputers, VORPAL has been designed as a parallel code. Figure 3 shows the parallel speedup, the time a calculation takes on N processors compared to a single processor, on up to 16,848 processors on a Cray XT/4 at the National Energy Research Scientific Computing Center (NERSC). The problem size of 768x512x512 grid cells was kept constant for the different numbers of processors, resulting in only 23x23x23 cells per processors on the largest number of processors. VORPAL therefore can take advantage of largest-scale parallel computers.

**First results:** Figure 4 shows a VORPAL simulation of the formation of a positively charged bow and a negatively charged wake around a perfectly dielectric spherical body. The plasma conditions are consistent with the Moon immersed in the solar wind. Simulations like this one can be used to study effects of the charging on the solar lit, the dark and the terminator region. In future simulations, we are planing to include emission of photo-electrons.

**Figure 4:** VORPAL simulation of the wake formation behind a perfectly dielectric spherical charging object (green), showing the negatively charged wake (blue) and a positively charged bow (red). Plasma conditions are consistent with the Moon immersed in the solar wind.

**References:**